The Retrieval of recent-decade ground deformation time-series of Chongming Island in Shanghai with multi-platform MT-InSAR analysis

Chengfang Yao1,2,3, Qing Zhao1,2,3*, Jingjing Wang1,2,3
1 Key Laboratory of Geographical Information Science, East China Normal University, Shanghai, China
2 Chongming ECO Institute, East China Normal University, Shanghai, China
3 School of Geographic Sciences, East China Normal University, Shanghai, China

Abstract

Ground deformation caused by estuarine deposit compaction in Chongming Island of Shanghai could last for decades or even longer. The combination of different deformation time-series retrieved by multi-temporal interferometric synthetic aperture radar (MT-InSAR) can continually monitoring the long-term deformation. In this work, we combined the deformation time-series derived by three SAR satellite image subsets, including Radarsat-2 Multi-Look Fine (RST-2MF) data, Radarsat-2 Wide (RST-2W) data, and Sentinel-1A (S1A) data spanning the time period between 2007 and 2017. The error budget of the combination of three-platform MT-InSAR deformation time-series is evaluated.

Keywords: MT-InSAR; Multi-platform; Error analysis; ground deformation

1. Introduction

The shallow strata in Chongming Island are formed late, and most of them are marine continental interactive sedimentation. The large void ratio, high water content and incomplete natural consolidation process of soil layer lead to significant compression deformation. Statistics show that the maximum land subsidence was more than –500 mm, and the subsidence rate exceeded –50 mm/year from 1995-2005 in the reclamation area of eastern Chongming Island. Due to the long land formation in the west of Chongming Island, the subsidence rate only reached –5.0 mm/year in the same period. Serious ground subsidence can not only damage public infrastructure and buildings, but also lead to natural disasters such as seawater backflow and storm surge. Therefore, it is significant to understand the long-term deformation of Chongming Island, especially in recent decade.

2. Study area

Chongming Island（121.16°E~121.9°E， 31.45°N~31.85°N）in Shanghai is located at the estuary of the Yangtze River, which is formed by silt deposits at the downstream of the Yangtze River. Since 1950, in addition to the sedimentation of the Yangtze River, Chongming Island has also experienced several artificial reclamations, which has expanded from less than 600 km^2 to 1269 km^2. The island is not only the third largest island in China, but also the world's largest estuarine alluvial island. The length of the island is 80 km and its width from north to south varies between 13 and 18 km. The terrain is quite flat with more than 90% of the land is located between 3.21 and 4.20 m above sea level. Figure. 1 shows the map of the study area.

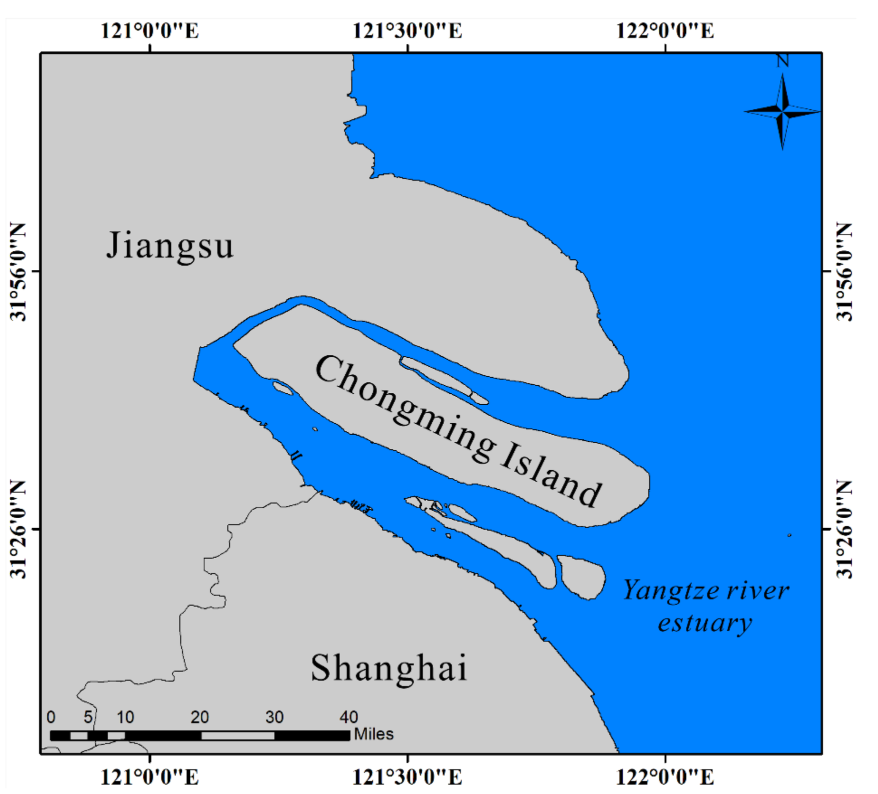

Figure. 1 Location of Chongming Island

3. Data and Methods

3.1 SAR data

Specifically, three independent Synthetic Aperture Radar (SAR) datasets (RST-2MF, RST-2W and S1A) were used to investigate ground subsidence in Chongming Island. The first dataset consisted of 21 SAR images, acquired by the Radarsat-2 sensors in the multi-look fine (MF) mode from August 2009 to December 2013. The second SAR dataset was acquired by the Radarsat-2 sensors in the wide mode, from January 2012 to December 2016 and consisted of 44 SAR images. The third dataset consisted of 120 SAR images, acquired by the S1A sensors from July 2015 to June 2020.

3.2 Methods

The three SAR datasets were independently processed by employing the multi-pass Small Baseline Subset (SBAS) algorithm[1]. SBAS is a well-established technique that allows the detection of the temporal evolution of Earth's surface deformation by generating mean LOS velocity maps as well as LOS displacement time-series. We combined deformation time-series of time-overlapped datasets by using Singular Value Decomposition (SVD) method [2] and then calculate the combination error with decoherence as the error source by the error propagation law. The standard deviation of the decoherence phase noise can be calculated as [3]:

$$\sigma_k{}^2 = var(\psi_k) \cong \frac{1-\gamma_k^2}{2L\gamma_k^2}$$

In the above formula, **L** is the number of looks used to perform the multi-looking operations and **k** is the coherence of the k-th differential interferogram at the given location of the generic radar pixel.

4. Results

By applying the SBAS technique, the relevant RSD-2MF (2009-2013), RSD-2W (2012-2016) and S1A (2015-2020) line-of-sight (LOS)-projected displacement time-series were recovered. Since the horizontal deformation is less than the up-down component, we focus on the generation of combined long-term vertical displacement time-series covering the period from 2009 to 2020. RSD-2MF and RSD-2W overlap about 1 year, form 2012 to 2016, meanwhile, RSD-2W and S1A overlap 1 year, form 2015 to 2016. Combination of the three deformation time-series, RSD-2MF+ RSD-2W+S1A, was performed using SVD method. Figure 2 shows the mean deformation rate of the vertical deformation in the Chongming Island, as retrieved by three SAR datasets and three deformation time-series' combination.

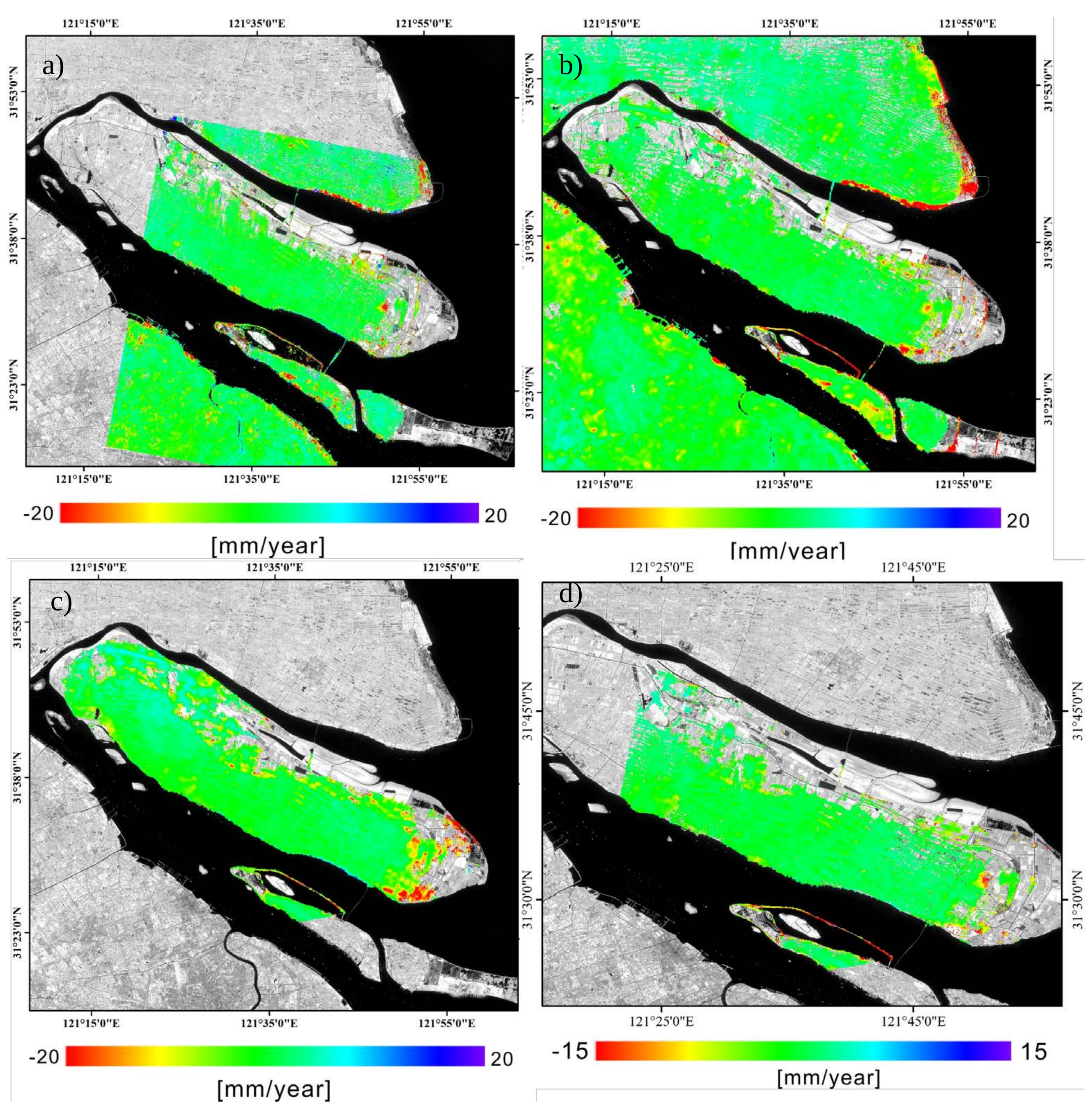

Figure. 2 Geocoded map of the mean (vertical) deformation velocity of Chongming Island, as retrieved by a) RST-2MF vertical deformation time-series during the 2009-2013, b) RST-2W vertical displacement time-series during the 2012-2016, c) S1A vertical deformation time-series during the 2015-2020, d) combining RST-2MF, RST-2W and S1A vertical deformation time-series during the 2009-2020.

Aiming at the noise caused by decoherence as the source error of SVD method, the error propagation theory is applied to all common high coherence points in the study area, so as to obtain the combination error distribution of RST-2MF, RST-2W and S1A in Chongming Island. As show in Figure. 3, the error distribution of Chongming Island SVD method with a mean value of 5 mm and a standard deviation of 4 mm is obtained by error propagation method.

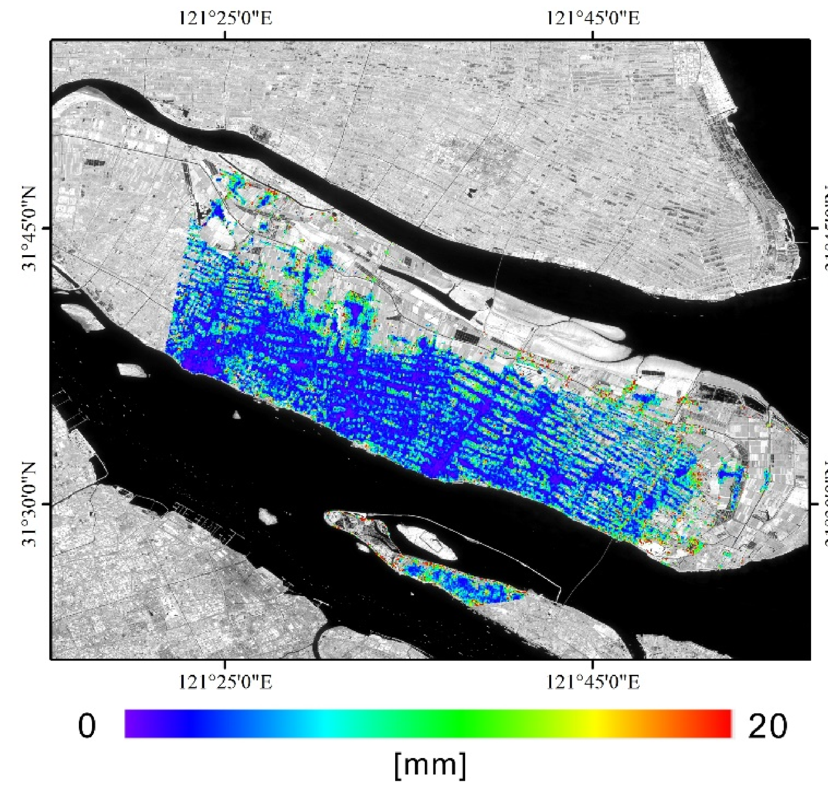

Figure. 3 Combination error distribution of RST-2MF, RST-2W and S1A.

5. Discussion

The RST-2MF+RST-2W+S1A deformation time-series shows that 98% of high coherence points of the cumulative deformation variables in the study area in recent decade are distributed between –120 mm ~ 20 mm, and the corresponding annual average deformation rate is distributed between –15 mm/year ~ 2 mm/year. The deformation rate of some reclamation areas in the east of Chongming exceeds –15 mm/year, and the cumulative settlement in recent decade has reached –200 mm. The deformation time-series at this point is shown in the figure below. The deformation mainly occurred in 2009-2014, with 150 mm settlement, while in 2015-2020, only 50 mm settlement occurred. This time series indicates that the ground deformation rate is decreasing and the ground surface is stabilizing.

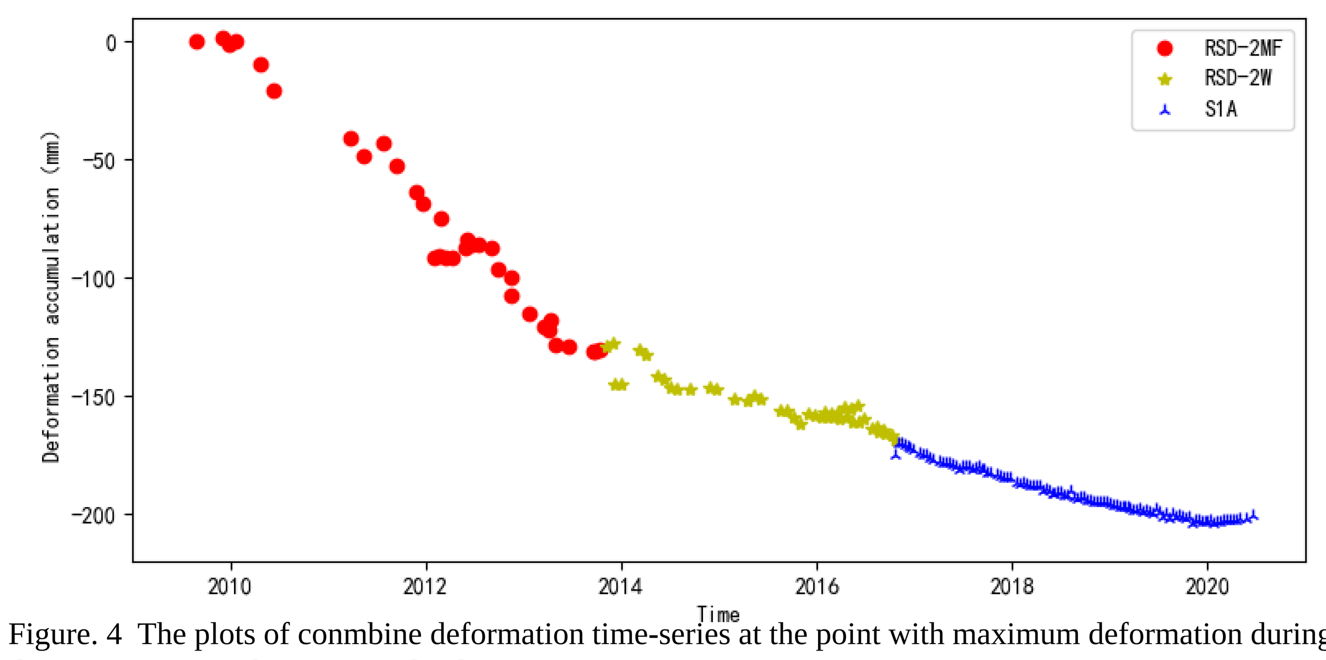

Figure. 4 The plots of conmbine deformation time-series at the point with maximum deformation during the 2009-2020 in Chongming Island.

6. Conclusion

In this study, the recent-decade ground deformation time-series of Chongming Island in Shanghai was retrieved with multi-platform MT-InSAR analysis. The deformation measurements for three different periods show similar spatial distributions, and they reveal that the deformation trends are consistent across Chongming Island at different periods. . By using SVD the deformation time-series derived by RST-2MF, RST-2W and S1A were combined. The results show that most areas of Chongming Island was stable, but obvious ground subsidence occurred in the reclamation areas in the eastern Chongming Island and its deformation mainly occurred in 2009-2014, gradually decreased with time. The combination error budget is obtained through the error propagation law, to quantitatively expressing the quality of the combination.

Major References

[1] P. Berardino, G. Fornaro, R. Lanari, and E. Sansosti, "A new algorithm for surface deformation monitoring based on small baseline differential SAR interferograms," *IEEE Transactions on Geoscience and Remote Sensing*, vol. 40, no. 11, pp. 2375-2383, 2002, doi: 10.1109/tgrs.2002.803792.

[2] L. Yu, T. Yang, Q. Zhao, M. Liu, and A. Pepe, "The 2015–2016 Ground Displacements of the Shanghai Coastal Area Inferred from a Combined COSMO-SkyMed/Sentinel-1 DInSAR Analysis," *Remote Sensing*, vol. 9, no. 11, 2017, doi: 10.3390/rs9111194.

[3] J. Tough, D. Blacknell, and S. Quegan, "A statistical description of polarimetric and interferometric synthetic aperture radar data," *Proceedings of the Royal Society of London. Series A: Mathematical and Physical Sciences*, vol. 449, no. 1937, pp. 567-589, 1995.